

Helium- to Hydrogen-Ion Ratios in the Inner Magnetosphere

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The solar extreme-ultraviolet radiation at 304 angstroms, which is resonantly scattered from helium ions has been proposed as a possible candidate for imaging of the magnetosphere.¹ The spatial distribution of the helium-ion density in the magnetosphere determines the amount of scattered 304-angstrom energy that reaches the detector from an element of solid angle along a given line of sight. The energy reaching the detector is the sum of all the sources in the line of sight, so that some a priori knowledge of the average spatial and temporal distribution of the helium ions would be helpful in deconvolving the images of the magnetosphere. Models that have been used to simulate a magnetosphere image from helium ions have approximated the spatial distribution by assuming a constant helium-ion density above some base altitude on a given L shell² or, alternatively, a constant helium ion-to-total density ratio.³ Total density in the magnetosphere is assumed to be represented by hydrogen ions. The behavior of the helium-to-hydrogen-ion ratio will be important in creating models of the ion composition of the inner magnetosphere, in understanding the physics of the light ions, and in interpreting images of the magnetosphere obtained using the scattered 304-angstrom radiation.

With several years of data from the Retarding Ion Mass Spectrometer on

the Dynamics Explorer 1 now available, covering both high and low solar activity, it seems an advantageous time to examine the helium-to-hydrogen-ion density ratio in more detail and, in particular, to examine how this ratio varies in the plasmasphere. The data cover the declining phases of the solar cycle from near maximum to minimum, all seasons, and most local times. The same instrument is used for both phases of the solar cycle so that it is possible to follow changes in the ratio with the solar cycle with no instrument cross calibrations. Densities are derived from each sample using the method described by Comfort et al., 1982,⁴ which requires that the ion-distribution function be near Maxwellian. Derived density values are confined mostly to the plasmasphere as a result of this restriction. The data were taken between October 7, 1981, and December 31, 1984, and the full data set is plotted in figure 30, in which gray represents data taken during high solar activity ($P > 150$) and black represents data taken during low solar activity ($P < 150$).

A preliminary examination of the data indicated that the ratio varied most with radial distance, r , and secondly with solar activity, P . The dependence on season, local time, geomagnetic activity, and latitude appeared to be much weaker than with r or with P . However, the spread of the ratios is large, due in part to the variation with r and P . In order to see the weaker dependencies and to model the behavior of the ratio, the helium-to-hydrogen-ion density ratios were detrended on r and P by assuming that the ratio is separable into products of

functions of each independent variable, i.e.:

$$R(r, P, Kp, \dots) = f(r)g(P)h(Kp)\dots \quad (1)$$

This treatment assumes that the independent variables are not correlated. The total data set is first fit to an analytical function of r , $f(r)$. The data are then detrended on r by dividing each data point by the value of the function $f(r)$. An analytical function of P , $g(P)$ was then fit to the ratios which have been detrended in r . The measurements were then detrended in P and the r dependence fit again using the same functional form for $f(r)$ as before. The dependence on both r and P , i.e., $f(r)g(P)$, was then removed from each data point in the original data set. The data, adjusted for both the r and the P dependence, are then given by:

$$R_d = h(Kp)\dots = R/Cf(r)g(P) \quad (2)$$

where C is a normalizing constant defined so that the average value of $\langle R_d \rangle = 1.0$.

Two very basic characteristics of the ratio of helium-to-hydrogen-ion densities in the plasmasphere are apparent in this study. One is that the ratio decreases with r in the plasmasphere, and the other is the strong dependence of the density ratio on solar activity. Histograms of the ratio for the Dynamics Explorer 1/Retarding Ion Mass Spectrometer data for low and high solar activity show a dramatic difference in the distribution of the samples, which emphasizes the importance of the solar input. For high solar activity, the histogram (after

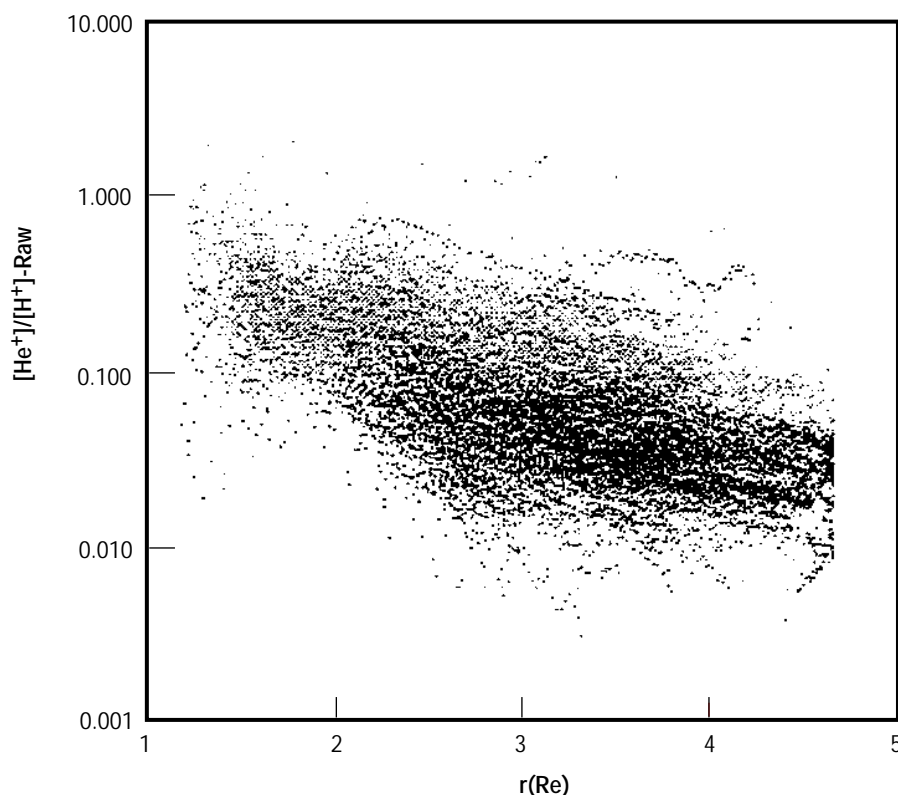


FIGURE 30.—Full data set taken between October 7, 1981, to December 31, 1984.

adjusting for the r dependence) is a broad distribution of values with an overall mean ratio of 0.25 (fig. 31). For low solar activity, there is a narrow distribution (fig. 32); the mean-adjusted ratio of which is 0.10. These values agree with previously published results from other satellites; their importance lies in the fact that they represent different phases of the solar cycle but are measured by the same instrument. These data are qualitatively consistent with a model of the plasmasphere developed, and being updated, by researchers (principally P.G. Richards) now at the University of Alabama in Huntsville. Results from this model indicate that

the ratio increases with increasing solar activity⁵ and decreases with increasing radial distance.

The importance of being able to accurately model helium-to-hydrogen-ion density ratio in the plasmasphere should not be overlooked. In order for images at 304 angstroms to represent the plasma density and not just helium ions in the plasmasphere, the relation between helium-ion density and the total density must be known. The data presented here suggest that the relationship can be represented by equation (1). In order to correctly deconvolve images of helium-ion-scattered, 304-angstrom light, or to

represent the results as total density, this relationship must be taken into account.

MSFC has found through a statistical study that the helium- and hydrogen-ion ratio varies with geocentric distance (or altitude) and that its variation in the plasmasphere, before any corrections are made, is about an order of magnitude from about 1 Earth radius to 4.5 Earth radii, decreasing with increasing geocentric distance. The ratio varies significantly with the solar cycle, being greater for higher activity than for low. The ratio has no apparent dependence on geomagnetic activity and is weakly dependent on the day of year, local time, and latitude after adjustments have been made for the distance and solar activity dependence. More detailed study is needed to understand the remaining spread in the data for any of the given variables. Such studies will need to consider geomagnetic activity history, ion temperatures, and production of helium and hydrogen ions in the ionosphere, among other things. Missions that image the magnetosphere will need to use models of the helium-ion distribution to help interpret the images, and MSFC provides a data-based model.

¹Johnson, C.Y.; Young, J.M.; and Holmes, J.C. 1971. Magnetoglow—A New Geophysical Resource. *Science*, 171, 379.

²Meier, R.R., and Weller, C.S. 1972. Extreme-Ultraviolet Resonance Radiation From Helium Atoms and Ions in the Geocorona. *Journal of Geophysical Research*, 77, 1, 190.

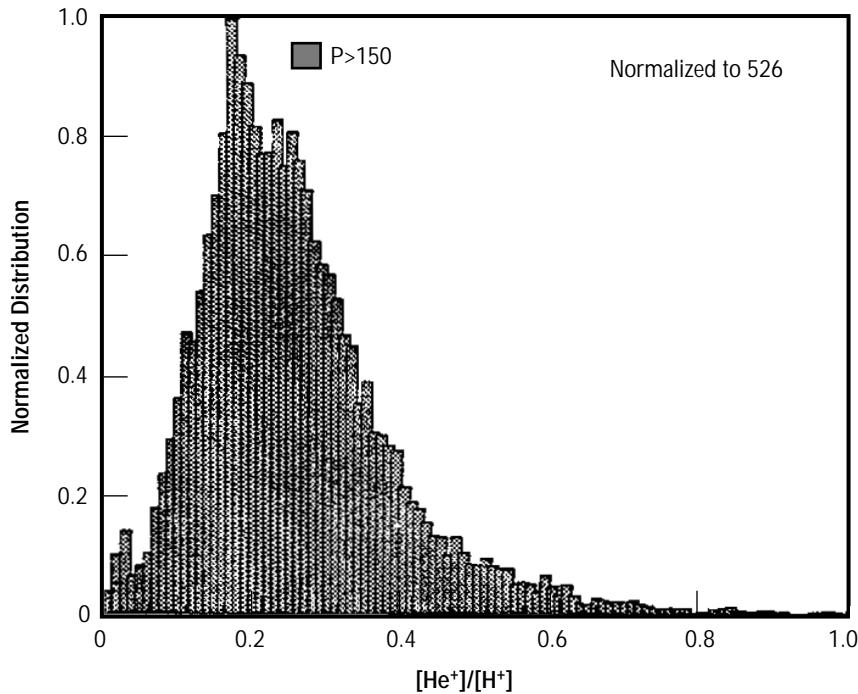


FIGURE 31.—Histogram of ratios for high solar activity.

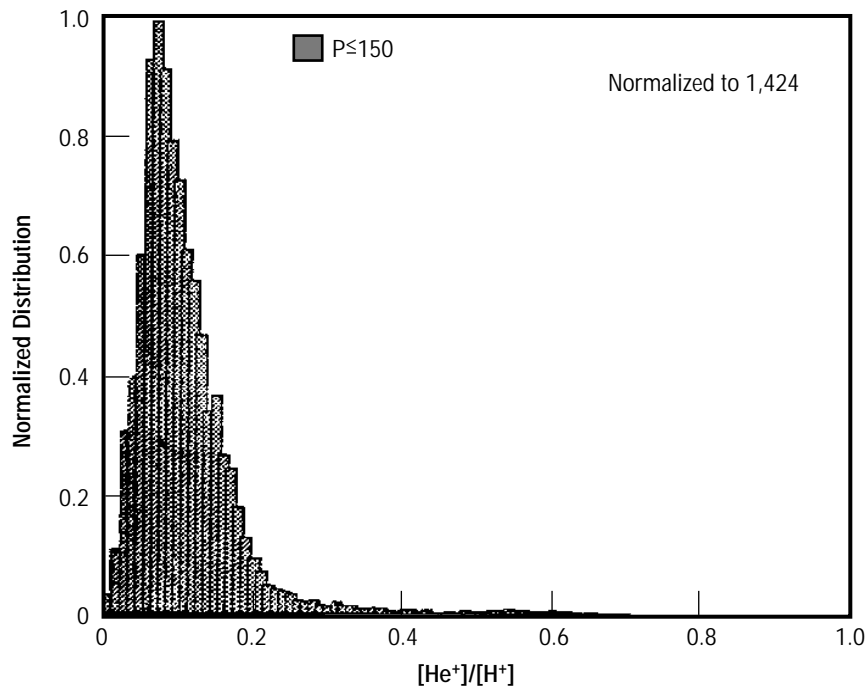


FIGURE 32.—Histogram of ratios for low solar activity.

³Meier, R.R. 1991. Ultraviolet Spectroscopy and Remote Sensing of the Upper Atmosphere. *Space Science Reviews*, 59, 1.

⁴Comfort, R.H.; Baugher, C.R.; and Chappell, C.R. 1982. Use of the Thin-Sheath Approximation for Obtaining Ion Temperatures From the ISEE 1 Limited Aperture RPA. *Journal of Geophysical Research*, 87, 5, 109.

⁵Newberry, I.T.; Comfort, R.H.; Richards, P.G.; and Chappell, C.R. 1989. Thermal Helium Ions in the Plasmasphere: Comparison of Observations With Numerical Calculations. *Journal of Geophysical Research*, 94, 15, 265.

⁶Young, D.T.; Balsiger, H.; and Geiss, J. 1982. Correlations of Magnetospheric Ion Composition With Geomagnetic and Solar Activity. *Journal of Geophysical Research*, 87, 9, 9077.

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